IITB-Monash Research Academy

Indian Institute of Technology Bombay | MONASH University

An Indian-Australian research partnership

| | | |
|---|---|---|
| **Project Title:** | **Development of Smart, Bioactive MOF-Integrated Composite Scaffolds for Enhanced Bone Regeneration** | |
| **Project Number** | **IMURA1324** | |
| **Monash Main Supervisor** (Name, Email Id, Phone) | Prof Neil Cameron, neil.cameron@monash.edu | *Full name, Email* |
| **Monash Co-supervisor(s)** (Name, Email Id, Phone) | | |
| **Monash Head of Dept/Centre** (Name, Email) | Prof. Matthew Hill, Matthew.Hill@monash.edu | *Full name, email* |
| **Monash Department:** | Department of Materials Science and Engineering | |
| **Monash ADGR** (Name, Email) | Prof Timothy Scott, Timothy.Scott@monash.edu | *Full name, email* |
| **IITB Main Supervisor** (Name, Email Id, Phone) | Prof. Sanjog S. Nagarkar sanjog.na@chem.iitb.ac.in; nagarkarss@iitb.ac.in | *Full name, Email* |
| **IITB Co-supervisor(s)** (Name, Email Id, Phone) | NA | *Full name, Email* |
| **IITB Head of Dept** (Name, Email, Phone) | Prof. Ruchi Anand head.chem@iitb.ac.in | *Full name, email* |
| **IITB Department**: | Chemistry | |

## Research Clusters:

**Highlight which of the Academy's CLUSTERS this project will address?**
*(Please nominate JUST **one.** For more information, see www.iitbmonash.org)*

| | |
|---|---|
| 1 | *Material Science/Engineering (including Nano, Metallurgy)* |
| 2 | *Energy, Green Chem, Chemistry, Catalysis, Reaction Eng* |
| 3 | *Math, CFD, Modelling, Manufacturing* |
| 4 | *CSE, IT, Optimisation, Data, Sensors, Systems, Signal Processing, Control* |
| 5 | *Earth Sciences and Civil Engineering (Geo, Water, Climate)* |
| 6 | *Bio, Stem Cells, Bio Chem, Pharma, Food* |
| 7 | *Semi-Conductors, Optics, Photonics, Networks, Telecomm, Power Eng* |
| 8 | *HSS, Design, Management* |

## Research Themes:

**Highlight which of the Academy's Theme(s) this project will address?**
*(Feel free to nominate more than one. For more information, see www.iitbmonash.org)*

| | |
|---|---|
| ***1*** | *Artificial Intelligence and Advanced Computational Modelling* |
| 2 | *Circular Economy* |
| 3 | *Clean Energy* |
| 4 | *Health Sciences* |
| 5 | *Smart Materials* |
| 6 | *Sustainable Societies* |
| 7 | *Infrastructure* |

## The research problem

*Define the problem*

Bone tissue engineering (BTE) has become a critical field in regenerative medicine due to the rising prevalence of bone-related conditions like osteoporosis, fractures, and bone cancer. While bone provides vital structural support and mineral storage, its natural regenerative capacity is often insufficient for large defects caused by trauma or disease.
Several classes of materials have traditionally been used to facilitate bone repair:

- **Autografts and Allografts:** These use natural bone tissue from the patient or a donor. While highly effective, they are limited by low availability, potential for disease transmission, and "donor-site morbidity".
- **Metals (e.g., Titanium alloys):** Widely used for load-bearing implants due to their high mechanical strength and wear resistance. However, they are biologically inert and often lack the ability to integrate seamlessly with natural bone.
- **Polymers (e.g., PCL, PLGA, Chitosan):** These organic materials are highly biocompatible and can be shaped into scaffolds that resemble the extracellular matrix. Their main limitation is inadequate mechanical strength and a lack of inherent bone growth factors.
- **Ceramics/Biocements (e.g., Calcium Phosphate):** These mimic the mineral component of bone but can be brittle and difficult to shape precisely for complex defects.

**Thus, newer approaches and the development of smart materials are crucial to overcome these challenges.**

## Project aims

*Define the aims of the project*

**Metal–Organic Framework Polymer Composite Scaffold for BTE**
Metal-organic frameworks (MOFs) have emerged as promising candidates for BTE by addressing the "multifunctional" needs of modern orthopedics.

1. **Inherent Bioactivity:** Unlike inert metals or simple polymers, MOFs are composed of metal ions (such as $Zn^{2+}$, $Mg^{2+}$ and $Ca^{2+}$) that act as therapeutic trace elements to actively stimulate bone cell proliferation and differentiation.
2. **Tunable Porosity and High Surface Area:** MOFs possess exceptionally high porosity, allowing them to act as highly efficient "nanocarriers" for the controlled release of drugs, proteins (like BMP-6), or growth factors.
3. **Smart Responsiveness:** MOFs can be engineered to be pH-sensitive or enzyme-activated, ensuring that therapeutic agents are released specifically in response to the physiological cues of the healing bone.
4. **Multifunctional Synergy:** They are compatible with a variety of materials and environment and the properties can be tuned to the extent of damage.
5. **Synergistic Composites:** By integrating MOFs into polymers or fibers, researchers create "MOF-integrated composites" that combine the mechanical flexibility of polymers with the bioactivity and drug-loading capacity of MOFs, significantly outperforming traditional single-material scaffolds.

**The project aims to achieve the following objectives:**

- **Selection and Design of Biocompatible Building Blocks:** Identify metal ions (e.g., $Zr^{4+}$, $Zn^{2+}$, $Mg^{2+}$ and $Ca^{2+}$) and organic ligands (e.g., amino acids, vitamins) that promote osteogenesis and angiogenesis while minimizing systemic toxicity.
- **Synthesis of High-Porosity MOFs:** Utilize solvothermal or liquid-liquid interfacial techniques to create MOFs with tailored pore sizes to facilitate cell attachment and optimized drug encapsulation.

- **Fabrication of Multifunctional Composites:** Integrate MOFs into organic matrices like hydrogels or electrospun polycaprolactone (PCL) fibers to create a 3D scaffold that mimics the natural extracellular matrix (ECM) and enhances structural integrity.
- **Controlled Therapeutic Loading:** Encapsulate bioactive agents such as BMP-6, BioGlass, simvastatin, or exosomes within the MOF pores to achieve high loading efficiency and prevent the burst release typically seen in conventional materials.
- **Engineering Stimuli-Responsive Release:** Design the composite to respond to microenvironmental triggers (e.g., pH changes or enzyme levels) for targeted, on-demand pharmacological release during different stages of bone healing.
- **Assessment of Synergistic Bioactivity:** Evaluate the composite's ability to simultaneously promote osteoblast differentiation, stimulate angiogenesis, and exert antibacterial effects to prevent implant-related infections.
- **Immunomodulatory Profiling:** Investigate the material's capacity to modulate macrophage polarization (e.g., toward the pro-regenerative M2 phenotype) to create a favourable immune microenvironment for tissue repair.
- Animal models to investigate bone regeneration in vivo (in Collaboration)
- Securing IP and assessment of technology readiness.

## How skills/experience of the IITB and the Monash supervisor(s) support the proposed project

*Highlight the purpose of the collaboration and/or the complementary skills/experience that you bring to the project. Do you have any joint or independent publications in the area of the proposed project?*

The proposed work involves the development of designer framework materials followed by integration with scaffolds for tissue engineering and investigation of bone regeneration performance.

Professor Nagarkar's research group works to design and develop new framework materials (MOFs, GOFs) for a variety of applications. The group is among the very few labs that have expertise in MOF glasses and liquids synthesis and characterization. (*Angew. Chem. Int. Ed.* **2017**, *56*, 4976; Physics and Chemistry of Glasses-European Journal of Glass Science and Technology Part B 66 (3) 107; small **2026** DOI: 10.1002/smll.202514343). The group has facilities to synthesize and characterize the framework materials (PXRD, TGA, DSC, Gas Adsorption Instrument, etc.). The group has access to advanced characterization techniques housed at the Sophisticated Analytical Instrument Facility (SAIF), IIT Bombay.

Professor Neil Cameron's research interests include scaffolds for tissue engineering. Recent work has focused on porous polymer scaffolds for bone regeneration and has included materials that incorporate bioactive glasses to enhance mineralisation (*Biomacromolecules*, **26**, 8548-8559 (2025)). Cameron has facilities for producing and characterising bone scaffolds, and collaborates with researchers who have access to animal models to investigate bone regeneration in vivo. The Faculty of Engineering at Monash provides a managed, open-access Category 2 bio-lab for in vitro cell culture studies.

The expertise of both groups is complementary and is essential for the successful implementation of the project objectives.

## What is expected of the student when at IITB and when at Monash?

*Highlight how the project will gain from the students stay at IITB and at Monash*

At Monash, the student will prepare porous scaffolds incorporating MOFs and will study their potential to generate bone tissue in vitro and in vivo. The student will thus obtain a diverse skill set in materials science, biomaterials production/ characterisation, and cell biology.

## Expected outcomes

*Highlight the expected outcomes of the project*

The expected outcomes are:

- Development of new bone regeneration material
- Publications in high impact journal
- Intellectual property (IP)
- Technology/Product development
- Manpower training
- Knowledge transfer
- Fostering collaboration further by applying for joint India-Australia funding.

Ultimately, these advancements are expected to bridge the gap between theoretical research and practical implementation in orthopedics, dentistry, and maxillofacial surgery.

## How will the project address the Goals of the above Themes?

*Describe how the project will address the goals of one or more of the 6 Themes listed above.*

**Health Sciences**: The project will develop enhanced bone tissue engineering scaffolds, which address a major clinical gap – bone regeneration to replace large volumes of lost bone through trauma or disease.

**Smart Materials**: Incorporation of MOFs will give smart/responsive properties to the materials as well as delivery of bioactive ions important for bone regeneration (calcium, magnesium, zinc, zirconium,…).

## How well the IITB and the Monash supervisor(s) know each other

*Provide details of previous collaborations (if any). For new collaborators, have you had a chance to meet each other in person or through VC or Skype?*

Professor Nagarkar and Professor Cameron met in person during Cameron's visit to IIT Bombay in December 2025. During this visit the they had a brainstorming and the outline of the project was finalized. They have also exchanged several emails regarding the preparation of this project outline.

## Potential RPCs from IITB and Monash

*Provide names of the potential research progress committee members (RPCs) and describe why they are most suited for the proposed project*

Monash: Professor Jess Frith, Professor Laurence Meagher, Professor John Forsythe
IIT Bombay: Professor Sameer Maji, Professor Prakriti Tayalia, Professor Rohit Srivastava

## Capabilities and Degrees Required

*List the ideal set of capabilities that a student should have for this project. Feel free to be as specific or as general as you like. These capabilities will be input into the online application form and students who opt for this project will be required to show that they can demonstrate these capabilities.*

**Mandatory:** Master's Degree in Chemistry
**Desirable:** Prior experience, such as an internship or project work, is desirable.

## Necessary Courses

*Name three tentative courses relevant to the project that the student should complete during his/her coursework at IITB (the student will require to secure 8 point in these courses)*

CH-405: Advanced Transition Metal Chemistry
CH-852: Chemistry of Heterogeneous Catalysis
CH- 820: Structure Analysis by Diffraction Methods

## Potential Collaborators

*Please visit the IITB website www.iitb.ac.in OR Monash Website www.monash.edu to highlight some potential collaborators that would be best suited for the area of research you are intending to float.*

Monash: Professor Jess Frith; Professor Mikäel Martino.
IIT Bombay: Professor Sameer Maji, Professor Jayesh Bellare, Professor Prakriti Tayalia

K**eywords** relating to this project to make it easier for the students to apply.

MOFs, Bio-Materials, Tissue Engineering, Bone Regeneration